Fine Scale Modeling of Hydroclimate over California and the West

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The hydrological cycle is changing

- Examples of such changes are well documented:
  - Changes in snowfall & snow pack
    - e.g., Mote 2003; Mote et al. 2005; Knowles et al. 2006
  - Changes in streamflow
    - e.g., Cayan et al. 2001; Stewart et al. 2005; Maurer et al. 2007
  - Warmer air temperatures (esp. spring Tmin)
    - e.g., Dettinger et al. 1995; Easterling 2002
- May affect our water supply in coming decades

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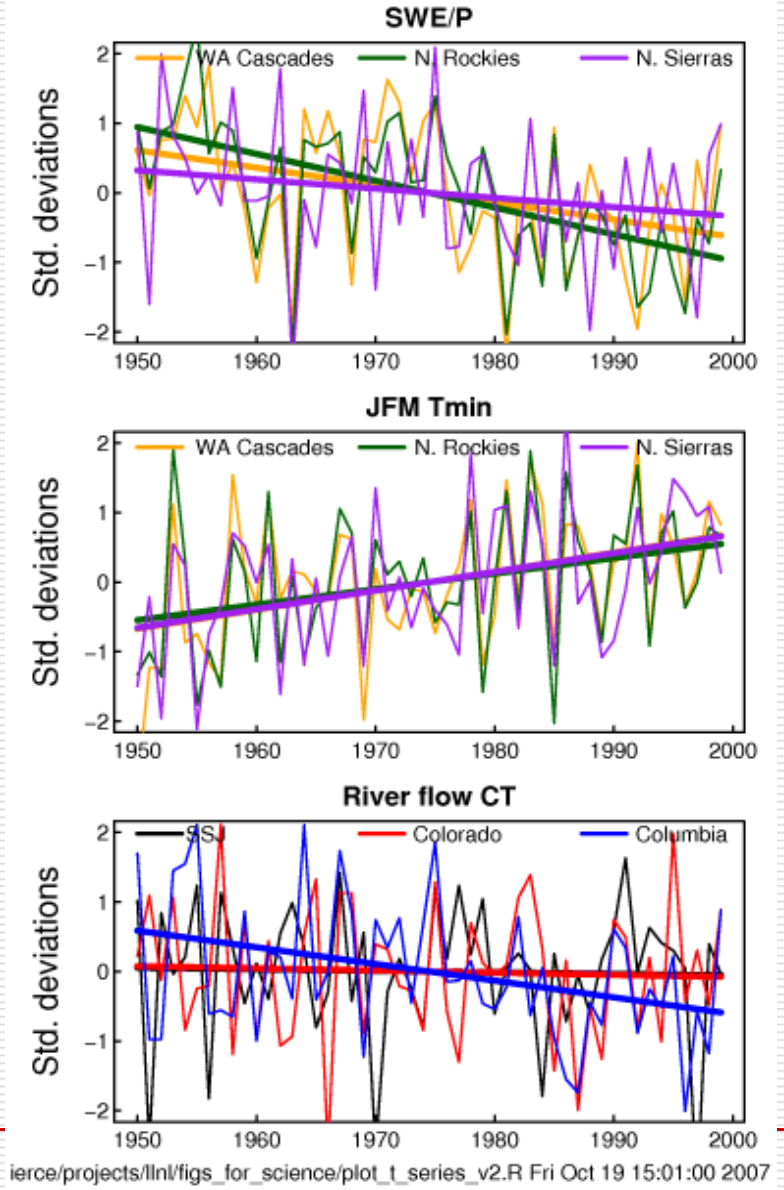
Can we say with confidence that these changes are due to human effects?

Detection and Attribution (D&A)

- Detection: are the changes *inconsistent* with natural variability?
- Attribution: are the changes *consistent* with anthropogenic forcing?

- Generate a *"fingerprint"* that encapsulates changes expected (from model runs)
- Assess trend in fingerprint in obs and models

Time series of key variables (obs.)



All variables have been normalized (fractionalized) by dividing by the CCSM3-FV control run mean over first 300 yrs.

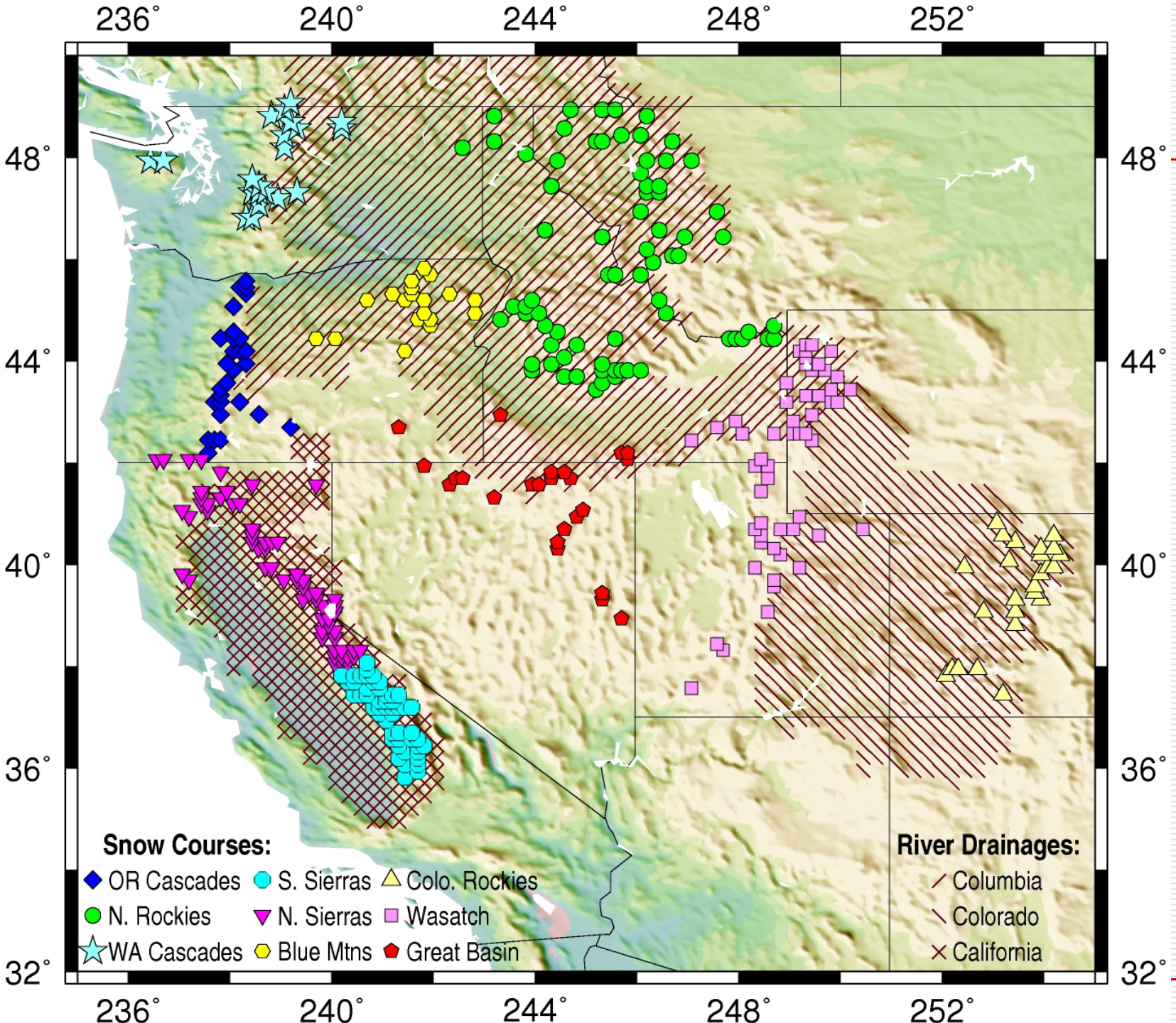
Necessary for the multivariate detection and attribution (D&A), so have same variance in each variable (the “units problem”).

Novel aspects

- *Multivariate* Detection and Attribution (D&A)
  - Not just temperature or streamflow alone
- *Regional*
  - Have to address problems of large amplitude natural variability
  - Global results downscaled to 1/8º to capture topographic effects
- *Related to the hydrological cycle*
  - Rare in formal D&A work
  - Immediate application to problems of practical importance

Overall scheme

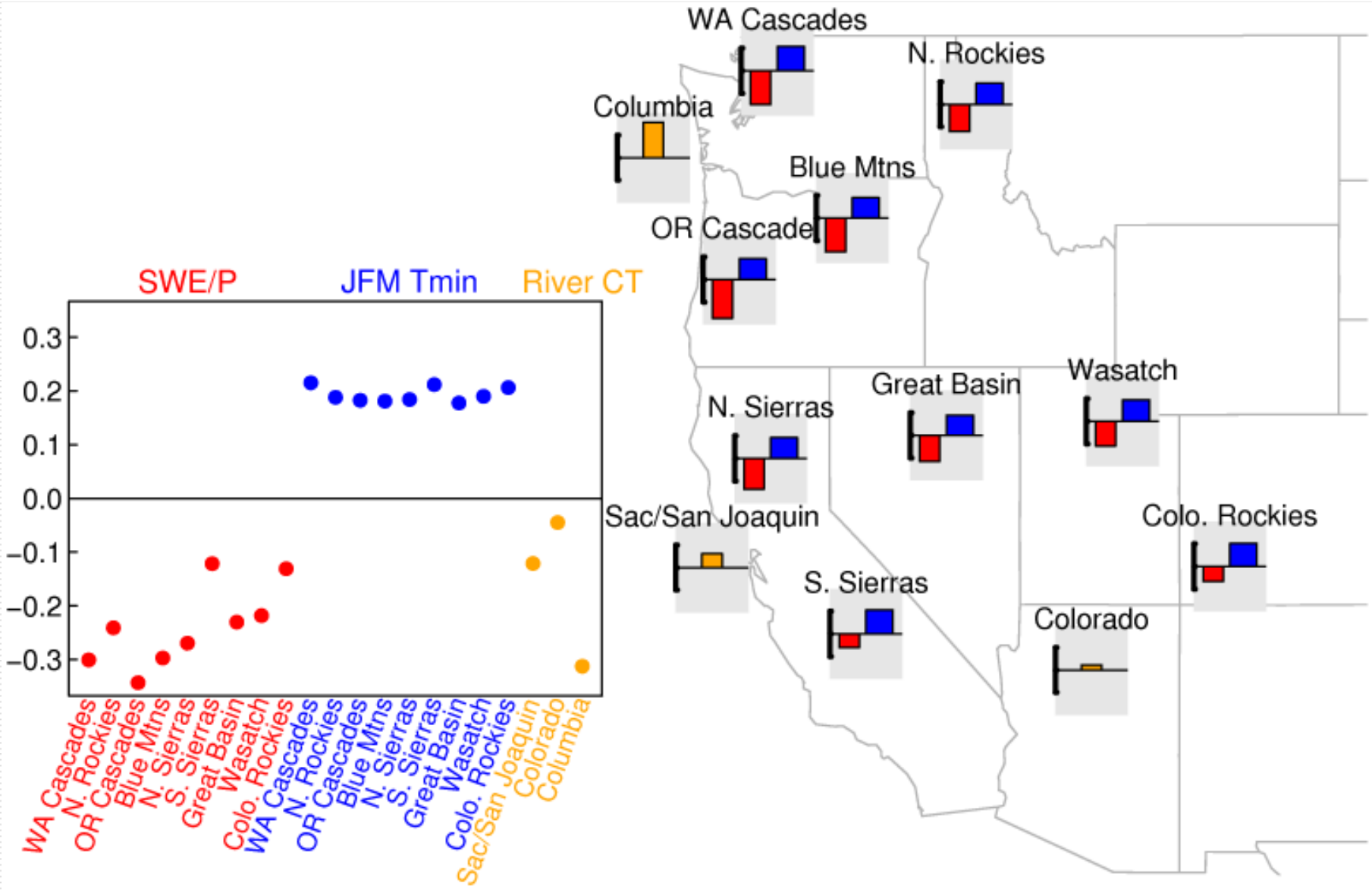
1. Start with global GCMs: control and anthropogenically forced runs
2. Downscale and apply to region of interest
3. D&A on 3 variables:
   - SWE/P (1 April Snow Water Equv. / Oct-Mar precip)
   - Temperature (examined JFM frost days daily minimum temperature)
   - River flow (examined JFM fraction and CT, center of timing)


236°
240°
244°
248°
252°
48°
44°
40°
36°
32°
Snow Courses:
OR Cascades
S. Sierras
Colo. Rockies
N. Rockies
N. Sierras
Wasatch
WA Cascades
Blue Mtns
Great Basin
River Drainages:
Columbia
Colorado
California

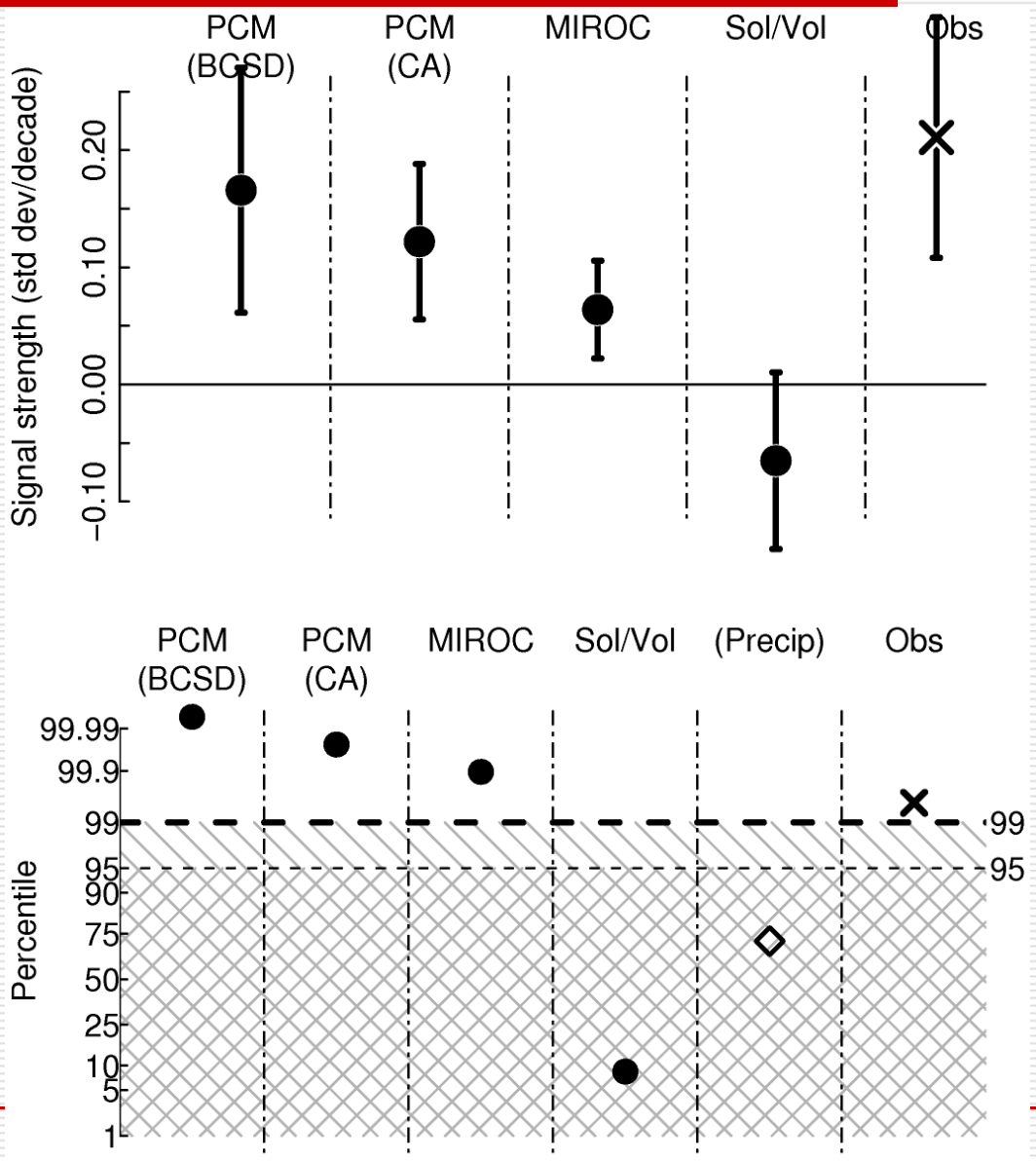
Models and data

- Control model GCM runs (1500 yrs)
  - 850 yrs CCSM3-FV (1.25^{O}x1^{O}; finer resolution than T85)
  - 750 yrs PCM (T42)
- Anthropogenically forced GCM runs, 1900-1999 (1400 yrs)
  - PCM (4 members)
  - MIROC (10 members)
- Regional statistical downscaling of GCM forcing
  - 2 methods, 12 km resolution
- VIC hydrological model (1/8 deg resolution)
- Observations, 1950-1999
  - Snow courses for SWE
  - UW, Maurer, PRISM for T and P
  - Naturalized flow from Colorado R. (Lee's Ferry), Columbia R. (Dalles), Sacramento and San Joaquin river

Multivariate fingerprint



Ensemble signal strength & significance



Conclusion:

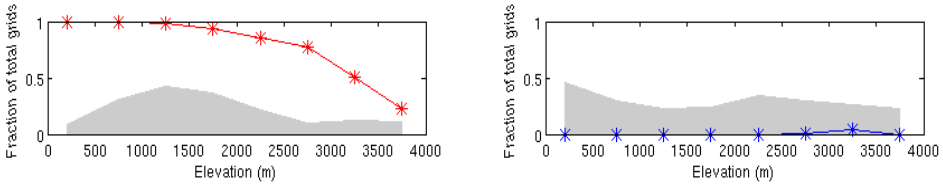
Hydrology of the western U.S. shows a clear signature of human-induced climate change

Changes with elevation

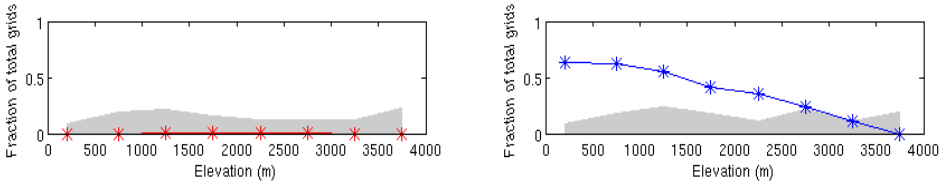
Red = increases

Blue = decreases

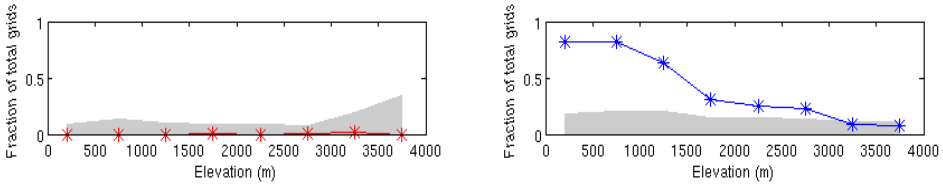
Temperature



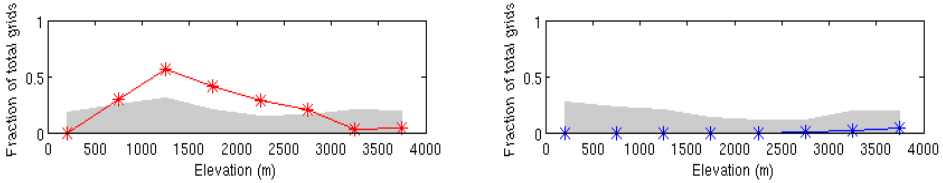
Snowy days



SWE/P



Runoff



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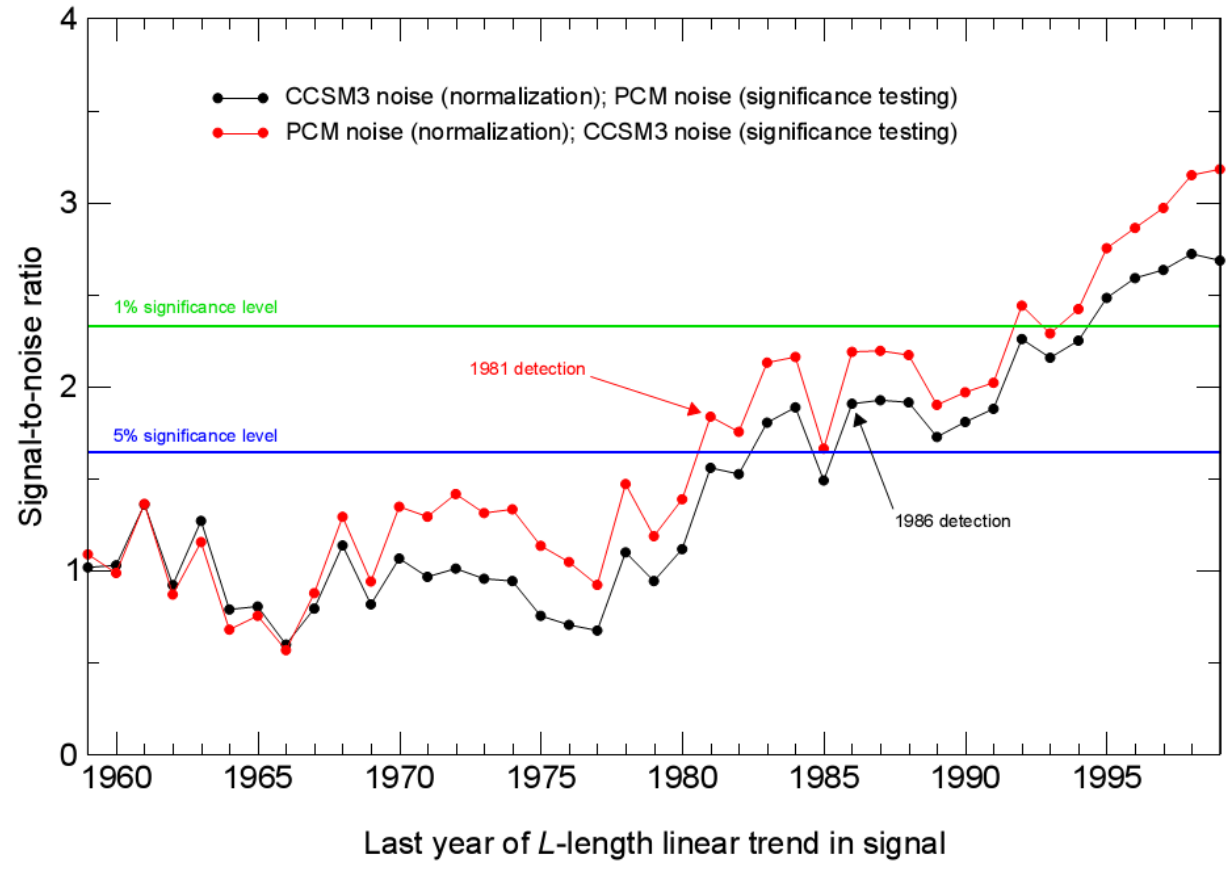
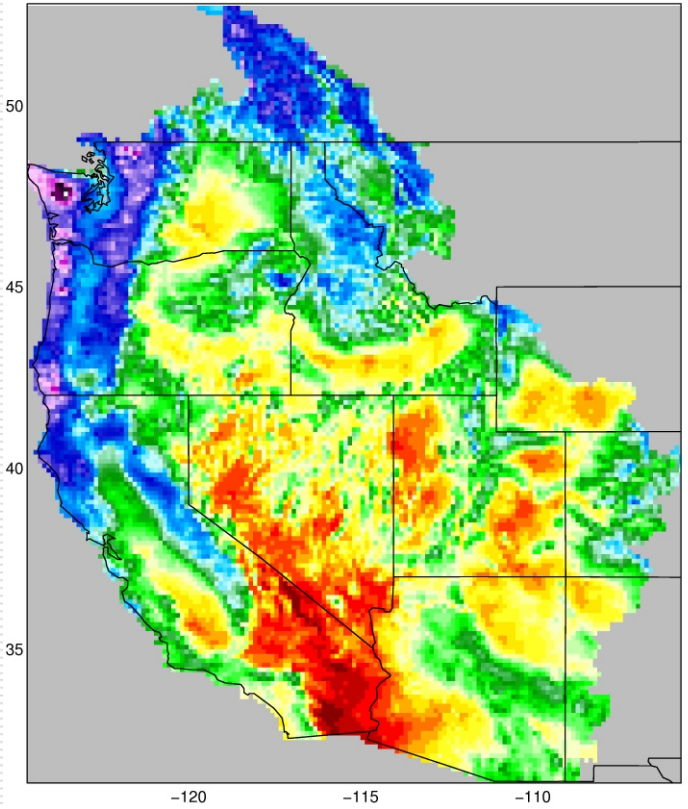
Time to detection



D&A helps us understand *today*. What about *tomorrow*?

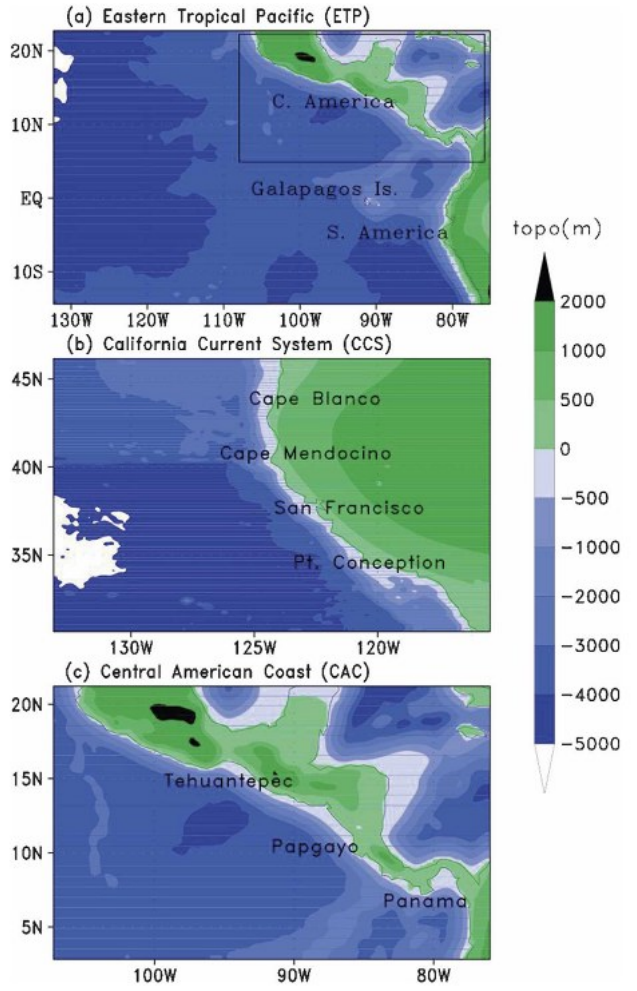
Looking Ahead

- Overall goal: High resolution, probabilistic projections of climate change impacts over California
- Downscaling
  - Statistical Techniques
    - Hidalgo and Dettinger – downscaling that preserves diurnal changes
    - Collaboration with Ed Maurer to compare to other statistical techniques
  - Collaborations with colleagues using WRF and RegCM
    - Participated in Regional climate model Enhancement and Baseline climate Intercomparison (REBI) project (N. Miller et al.)
    - Compare high-resolution simulations to observations and each other



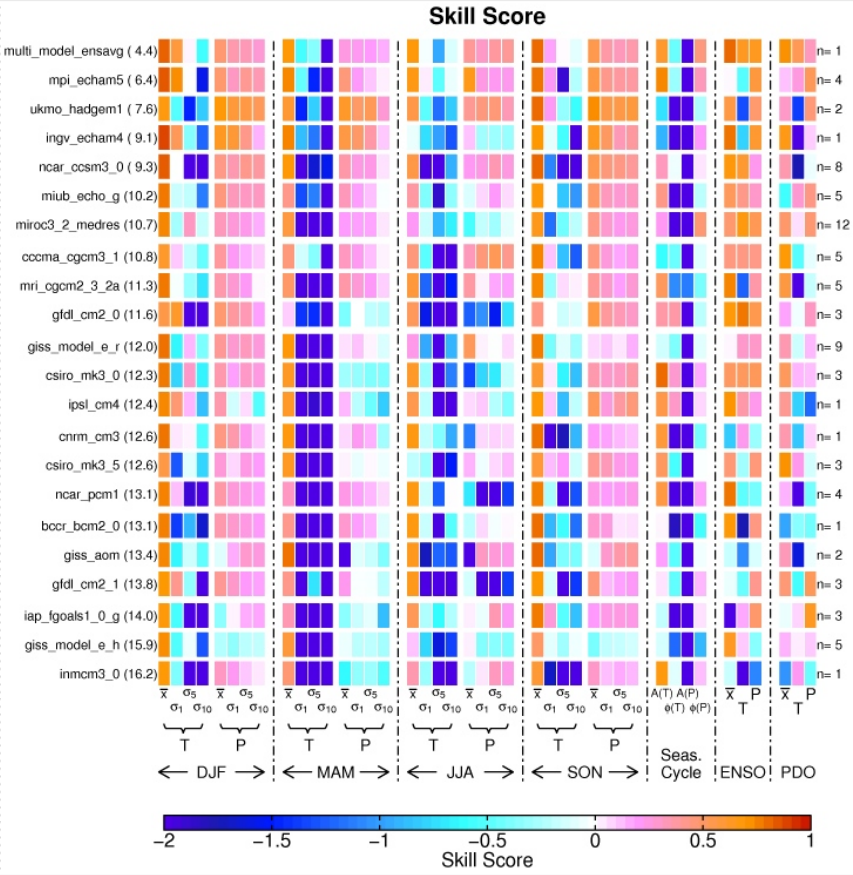
Looking Ahead

- Regional Spectral atmospheric Model (RSM)
  - Building on success of Kanamitsu and Kanamaru (2007), 57-year dynamical downscaling of NCEP/NCAR reanalysis at 10 km resolution (CaRD10)
  - Extending to future climate scenarios; goal is multiple ensemble members at 10 km resolution
- Coupled regional model (Seo, A. Miller)
  - Influence of ocean upwelling on coastal temperatures
  - Regions of persistent marine stratus – significant global errors, affects us too
  - Influence of local vegetation changes on regional climate



Looking Ahead

- Selecting global models for regional downscaling
  - How to best do this for a trustworthy regional result
  - Way to make best use of multiple global runs for our region's needs
- Probabilistic understanding
  - Mike Dettinger's "spaghetti" of future climate possibilities
  - How do global uncertainties propagate through to water availability, ecology, heat waves, etc.
- Higher spatial resolution
  - Marine layer / sea breeze effects are vital to energy consumption!



Conclusions

- Much previous work noting changes in snow cover, temperature, and river flow over the western U.S., but no formal D&A, nor multivariate, nor on such a fine scale
- Formal D&A analysis shows changes in western hydrology over 1950-99 are largely human-induced (est., 60%; ENSO and the PDO are also important in our region).
- Detailed agreement between model and obs. over past conditions gives confidence for regional climate projections and their impact on California.